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Some methods of upgrading of technologies of construction of wells for shale gas

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Based on the analysis of international practices the directions for improvement of the construction technologies for shale gas wells are worded. Particular attention is paid to the quality of the well construction, technologies of drilling-in and development of a payout beds.

According to expert assessments [1–3], the significant (more than 1,1 billion m^3) stocks of shale gas are concentrated on the territory of Ukraine and this opens the opportunities of replenishment of energetic resources at the cost of own gas mining. Shale gas belongs mainly to the diffuse gas in the pore -crack cavities connected with the peculiarities of layering pelitomorphic shale formations, including gas of closed pores and sorbed by mineral and organic substances, occasional to the low permeable reservoirs and causes the low yields of boreholes [2].

Today in Ukraine there is no experience of construction of wells for shale gas. Therefore it is important to study and generate the world experience, that gives an opportunity to improve the technologies of construction of wells.

The analysis of world experience of well construction

Specific features of the production of shale gas require the use of technologies of well drilling, aimed for improving of their performance. Construction of shale gas wells is performed with the using of the technologies of drilling horizontal bores and intensification of gas - using the multiphase hydraulic fracturing) (HF)[3-5].

Experience in the construction of wells in the Barnett, Woodford, Haynesville, Bakken, Fayetteville and other wells[3, 4] demonstrates that each shale gas well requires its own technology of development. This is due to the peculiarities of geological structure of the wells, properties of rocks and different nature of gas storage. On Fig. 1 the basic problems in drilling wells for shale gas are systematized. For drilling of horizontal bores the drilling muds on water and oil base are used. The horizontal bores are mainly fixed by the casing columnsand cemented. On the bed Bakken the boreholes are finished by the open bore or uncemented stem, on the wbed Fayetteville the tendency of open finishing of wells using cuffs and packers is also observed [4].

In [5] to intensify coming of gas the HF is considered using the technological liquids on the base of propan.

In [6, 7] the technology of guided coiled tubing drilling of horizontal bores is recommended in the conditions of depression for payout bed, It is soo called technology UBD (underbalanced drilling). Such a technology is a prospective and has a raw of advantages, in particular:

increase of mechanical boring speed;

prevention of pollution of the payout bed;
estimation of parameters of the the payout bed at real time mode through the use of a cable channel of communication and systems of directional drilling;
the possibility of passing of the wellbore in beds of small thickness and other.
For creation of depression in some case it is efficient to apply the nitrogen units of cryogenic type.
Coil tubing technologies are successfully applied for the intensification of gas production through technology RDS or radial drilling (company «Radial Drilling Services, Inc.», USA) and HF.

System of estimation of wells quality

The base of the structure of the management of quality of the facilities of oil and gas wells suppose the concept of quality and system of its evaluation [8]. A set of parameters, characterizing the oil and gas borehole from the position of fulfilling the main requirements in accordance with the project of development of the bed determines the quality of the well as the engineering structure.

In the general case, the quality of the well should be evaluated according the flexible hierarchical structure of criteria, depending on the purpose and trajectory of the well, kind and mining and geological drilling conditions and other factors. The upper level of the hierarchical structure should include creteria that characterize the trajectories of the well, its fixing, opening of productive horizons, as well as the environmental requirements.

Criteria of well quality

Geophysical	**Technological**	**Ecological**	**Others**
Assessment of resources of shale gas	Construction of adequate hydrodynamic models of bed	Construction of large number of wells	Preparing of highly qualified personnel for realization of innovating technologies
Studying of physical and mechanical collector properties of mine rocks in natural state	Choice of scheme of placement of wells and their shafts	Using of technologies of intensification of mining	Social
Construction of geological model of bed	Achievement of high quality of wells construction		
Studying of processes of cracks creation, their monitoring during FHF	Drilling of horizontal shafts in the producing formation		

Fig. 1. Problems of shale gas mining

There was proposed the open ierarchical structure of criteria of the quality of oil and gas wells, which allows their possible additions and exclusions on different levels of the hierarchy (Fig. 2). This will ensure more accurate assessment of the quality of drill depending on its purpose and peculiarities.

Geometric criteria assess the quality of the well according its trajectory to the design statement.

Criteria of fixing assess the reliability of fastening (readiness, reliability, maintainability) of well as the technical structure from the positions of the execution of its functional tasks. The assessment of the quality of the well under the criteria of fixing may be performed separately for casing column (including wellhead and downhole equipment) and separation of beds.

Criteria of drilling of productive beds assess the effectiveness of technology completion of the wells concerning the preservation of reservoir properties.

Ecologic criteria assess the quality of the well according the indicators of protection of subsoil and environmental protection. In the general case, the structure of environmental criteria is complicated, which is caused by the different character of environmental pollution. Its choice depends on the location of the well and the current system of environmental monitoring.

A system of criteria and principles for quality assessment can be implemented during the stages of design and construction the of wells [8], which gives the opportunity to formulate increased requirements to the projects in order to achieve a high quality of well construction. Principles of evaluation of quality of technologic operations.

At last the quality of the well depends on the list and sequence of technological processes, the compliance of their parameters with drilling and geological conditions etc. Thus, targeted control and management of technological processes is an integral part of the system of management of quality of well construction.

Technologies of deepening and completing of the wells are given by the relevant combinations of the basic operations. Each operation is characterized by a set of relevant parameters and system of specific restrictions on the parameters defining the quality of the operation.

In general, the assessment of the quality of technological operations is to identify the main and controlled parameters, forming of system of restrictions under the terms of the safe drilling operations, and ensuring the quality of the construction of the well, the rationale for the criterion of optimality and parameters of operations [8].

Criteria of well quality

Geometric criteria of well	**Criteria of fixing of well**		**Criteria of exposure of producing formations**	**Ecological criteria**
Coordinates of clearing	Casing string	Bordering of formations	Type and properties of drilling mud	Protection of depths
Intensity of curvature	Solidity	Height of raising of cement slurry	Hydrodynamic conditions (repression)	Environmental protection
Trajectory of exposure of productive formation	Containment	Degree of placement of cement slurry on the depth	Time of exposure of productive formations	

Forces of support during the moving of pipes columns	Technical condition	Degree of substitution of drilling solution	Construction of clearing zone of formation	
Cavernosity of shaft	Mouth and well equipment	Degree of cohesion of cement stone with casing string	Technology of secondary exposure	
		Degree of cohesion of cement stone with mine rocks	Parameter of correlation of productivities	
		Defects in cement stone		
		Presence of annulus packers		
		Casing pressures		

Fig. 2. Systematization of criteria of quality of wells

The efficiency of the technological operations of deepening of wells is defined by the criteria which correspond the minimum cost of construction of the wells. Criteria of efficiency of technological operations of completion of wells should be aimed at increasing the quality of the opening of productive horizons and reliability of the well as a technical facility.

System of assessment of quality of construction technologies of the wells should include the standards on the execution of each technological operation for the relevant drilling conditions. Standards should contain recommendations on the choice of values of parameters, monitoring and analysis and modification of the technological operation with the purpose of increase of its quality. Parameters of technological operations x = (x1, x2, ... xn)T are chosen of conditions for safe drilling operations, execution of restrictions φ(x) to ensure the quality of the well and the optimality of criterion Kl(x, a) of the effectiveness

$$\begin{cases} K_l(x,a) \to \min, \ l \in L, \ x \in D; \\ \varphi(x) \le 0, \end{cases} \quad (1)$$

where D – sphere of defining of parameters of technologic operations; a = (a1, a2, ... am)T – vector of model parameters.

So at the base of abovementioned we can propose 4 score system of assessment of the quality of technologic operations:

Very high – parameters of technologic operations correspond the adopted system of restrictions and grounded criterion of optimality;

high - parameters of technological operations meet the accepted system of restrictions and at least one of them does not meet the grounded criterion of optimality; *satisfactory* - parameters of technological operations meet the accepted system of restrictions and at least one of them does not meet the limits of ensuring the quality of the facilities of the well; *unsatisfactory* - parameters of technological operations meet the accepted system of restrictions and at least one of them does not meet the conditions of safe conducting of drilling operations.

Technologies of drilling of productive beds

Preservation of the natural permeability of productive beds is an essential requirement to technology of completion of wells.Its efficient solution influences on the performance of the wells and the degree of extraction of carbohydrates in the process of developing of beds. Prevention of pollution of the productive bed requires a comprehensive and detailed approach to the resolving, and is based on the scientific basis. In general the methods of prevention of pollution of the productive bed cover the choice of the well design, technologies of initial and secondary drilling of the bed, the choice of drilling mud system, control of hydro - and thermodynamic conditions of drilling of the bed [9]. The choice of design of the well and implementation of each technological operation at the stage of its completion should be subject to the requirements of the qualitative drilling of productive horizons.

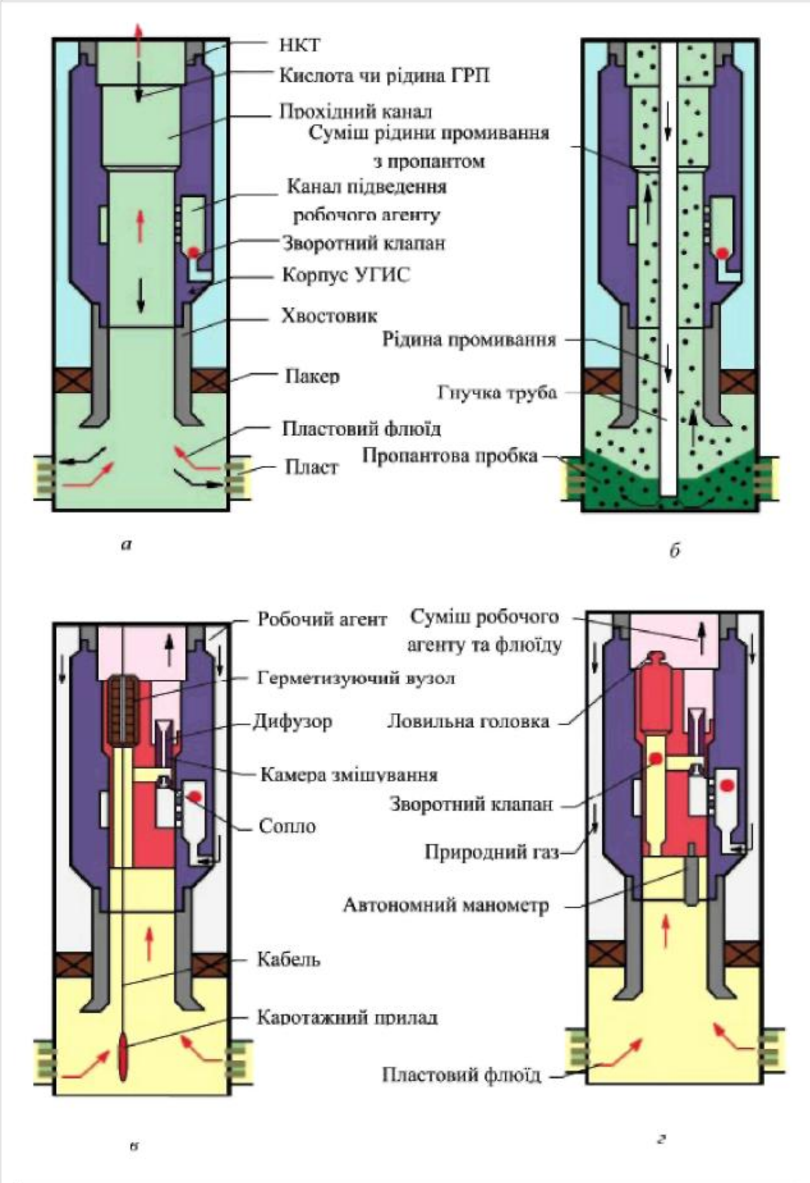

Fig.3 Scheme of components УГИС-(31–40) Ш for development and operation of wells: *а* – work with the body УГИС for acid treatment, HF, fontane operation (valve is closed); *б* – work with the body УГИС for watering of face from propant with the help of coil tubing (valve is closed); *в* – work with logging ejector for avoiding of products of reaction and liquid HF from the bed, geophysical researches in the mode of coming, registration of indicator curves (valve is open); *г* – work with hydrodynamic ejector for avoiding of products of response and liquid HF from the bed, appeal of coming, registration of indiocator curves, mining of oil and condensate (valve is open) and registration of curves of pressure restoring (valve is closed)

The most reliable technologies for the prevention of pollution of productive of the world. It has been proved that the potential of technologies of wells completion can be achieved only during the drilling of the horizons UBD (with a dettachable differential pressure) [10], which are used by leading drilling companies productive beds on depression.

$$p_j(z_\Pi) \leq p_\Pi + \Delta p^{+}_{\max}, \quad (2)$$

where $pj(z\Pi)$ – hydrodynamic pressure in the well at the depth

$z\Pi$ of productive bed during the execution

j-oï technological operation; $\Delta p^{+\max}$

maximum acceptable repression on the bed (for example, during the drilling of the bed at the process of mechanical drilling).

System for the analysis of rheological properties is intended for processing data of the rotational viscosity of drilling technological liquids, built on a strict solution of the basic equation of rotational viscosity and takes into account the information richness of experiences [11]. Class of rheologically stationary models includes common models in drilling practice of Newton, Shvedov-Bingam, Ostwald, Gershe La Balkli, Shulman-Caisson, and biviscous models like

$$\dot{\gamma} = \begin{cases} \dot{\gamma}(\tau, a^{(1)}), \tau \le \tau^*; \\ \dot{\gamma}(\tau, a^{(2)}), \tau > \tau^*, \end{cases}$$

where $a^{(1)}$, $a^{(2)}$ – rheological model properties for low and high gradients of rates of fault $\dot{\gamma}$; τ^* – border tension of fault which is defined after the resolving of equation $\dot{\gamma}(\tau, a^{(1)}) = \dot{\gamma}(\tau, a^{(2)})$.

The system allows the construction of adequate assessments of rheological models and properties, the matrix of covariances of assessments of rheological properties, batch processing array data, construction of barothermic and other equations of state of rheological properties. It is important for modeling of hydrodynamic processes (assessment of external capacity of drilling fluids [12], managing of hydrodynamic conditions (2) and others) to make effective technological decisions. The functionality of the system surpasses the well-known analogues.

The system of choosing of optimal formulations of drilling solutions is constructed using the model of the form (1) [13].

$$\begin{cases} E(x^{\nu}) \to \min, \ \nu \in \vartheta, x^{\nu} \in D^{\nu}; \\ \varphi(x^{\nu}) \le 0, \end{cases} \qquad (3)$$

where $E(x^{\nu})$ – criterion of optimality; x^{ν} – vector of concentrations of reagents of component composition; ϑ – class of acceptable sets of reagents; D^{ν} – area of determination of vector x^{ν}; $\varphi(x^{\nu})$ – system of restrictions for concentrations of reagents.

The peculiarity of the model (3) is a preliminary choice of local criterion $E(x\nu)$ of optimality of some set of possible ones, which corresponds the global criterion the best for the given conditions of drilling. Depending on the conditions of exposure of the productive bed, it is possible to use the various criteria of optimality: the cost of a volume unit of drilling mud, corresponding of certain indicators of the properties to the specified values, the external ability of flow of mud in the given interval of the well, relative decrease in the permeability of the core material, etc. Information support of model (3) is based on the results of experimental studies according the relevant plans.

For disclosure of low-penetrating productive beds [13] advises to conduct a two-stage procedure of choice of drilling mud. At the first stage, the basic formulations are to be chosen of the provision of the minimum value, and at the second - the optimal formulation of mud on the criterion of minimum interfacial tension on the border of phases mud filtrate - fluid. The decision making support system is created, which allows a free choice of the criterion of optimality and system of limitations, design, and maintenance of plans of experiments, the interpretation of their results, the search for optimal formulation of drilling mud. This system can be used to select the optimum recipe of processing of drilling mud in the process of well drilling.

Well development technologies

Well development resolves into the calling of the fluid flow, cleaning of the bottomhole formation zone of mud filtrate and other polluting adds,carrying out of the necessary works in order to increase the filtration characteristics of the bed and commissioning of the well. Parameters of all technological operations during the well development should meet the requirements of quality according (1). Technological liquids for development of wells should be selected using the model of the appearance (3).

To develop the shale wells with hydraulic fracturing the technologies of «EMPI - service» Ltd. can be effectively used which allow the implementation of the necessary technological processes for one using of set of tools with ejector pumps UGIS of series 11-20, 31-40 and 41-50 [14, 15], in particular: industrial-geophysical and hydrodynamic investigations of the hydraulic fracturing; HF through the ejector pump UGIS; removing of the working fluid HF and propant from the bed through UGIS;

Repeated industrial-geophysical and hydrodynamic investigations.

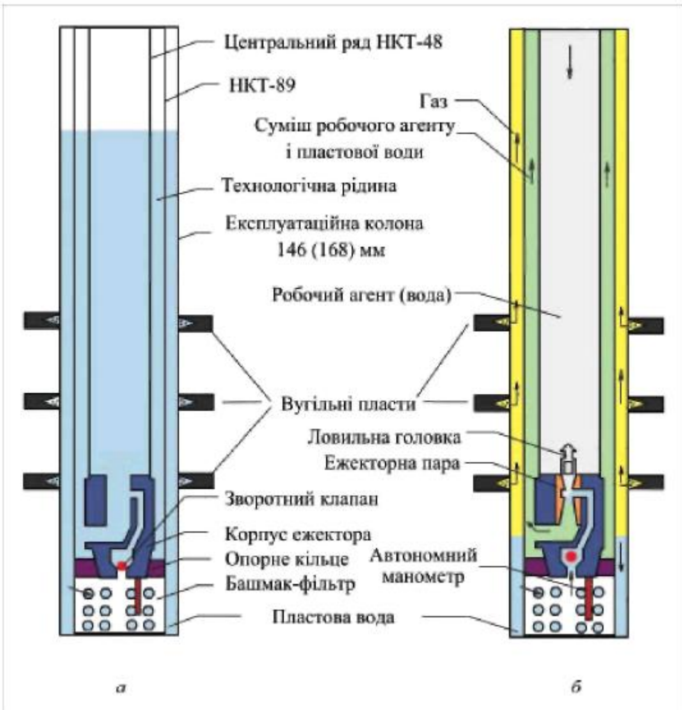

Fig. 4. Sheme of components of well equipment during the operation of gas well with the help of ejector pump НЕД-1В: *а* – installation of two-raw lift with the body НЕД-1В;

б – removing of liquid with the help of НЕД-1В

The technologies are used in the vertical and bent guided wells combining with coil tubing equipment. [14, 15].

Fig. 3 shows the scheme of components of the tool with the ejector pumps UGIS-(31–40)Ш for research and development of the well with abnormal low bed pressures (ALBP) with the help of HF. Here different detachable ejector devices are used with one body, as well as the reverse (fig. 3, в and г) and direct (fig. 3, а and б) circulation of liquids.

For exploitation of methane-coal and shale wells with ALBP the design of the plug-jet pumps НЕД-1В [16] is developped, which is used with two-line arrangement of pump-compressor pipes with a diameter of 48 and 89 mm. Ejector pumps НЕД -1В have high operational reliability in the presence of gas and mechanic impurities in the fluid, replacement of jet couples does not require the use of teams for overhauling of wells and cable equipment. Fig. 4 shows the diagram of the components of the well equipment for operation of gas wells with ALBP using the injector pump НЕД -1В. Technical water can be used as a working agent. To provide the technological requirements of operating gascompressor stations the scheme of components includes the use of two-raw lift on the entire length of the well. The scheme of components can be applied subject to free curvature of the wellbore.

Technologies of “EMOI-service” Ltd. with the using of ejector pumps UGIS are used at the beds of Russia [14, 15]. Ejector pump НЕД-1В has been successfully tested at methane and coil wells of Russian Federation.

At the base of mentioned in the article we can refer to the possible vectors of improvement of construction technologies of the wells for shale gas as follows:

system of assessment of quality of well construction;

system of assessment of quality of technological operations;

technologies preventing the pollution of productive beds due to the choice of properties of technological liquids and guidance of hydrodynamic situation in the well;

multifunctional ejector layouts and technologies of development and operation of the wells.

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